Current and Future Rocket Propulsion Testing at NASA Stennis Space Center

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ABSTRACT

Year 2000 has been an active one for large-scale propulsion testing at the NASA John C. Stennis Space Center. This paper highlights several of the current-year test programs conducted at the Stennis Space Center (SSC) including the X-33 Aerospike Engine, Ultra Low Cost Engine (ULCE) program, and the Hybrid Sounding Rocket (HYSR) program. Future directions in propulsion test are also introduced including the development of a large-scale Rocket Based Combined Cycle (RBCC) test facility.

SSC PROPULSION TEST CAPABILITIES AND ACTIVITY

NASA's Space Transportation Plan calls for both evolutionary and revolutionary advances in Space Propulsion as an enabling element for lowering the cost of access to space. Near-term and longer-term Space Transportation roadmaps have been developed (cf. Ref. 1) and are comprised of both chemical and non-chemical propulsion technologies required to enable 1st Generation (e.g., Shuttle), 2nd Generation (e.g., Reusable Launch Vehicle (RLV)), 3rd Generation (e.g., Airbreathers), and 4th Generation (e.g., non-traditional propulsion devices) space transportation.

In order to reduce the risk to flight programs, extensive ground testing is anticipated as part of the coming technology and/or vehicle development efforts. Therefore the entire suite of NASA development and test facilities must be prepared to accommodate the testing needs. This paper summarizes how the NASA John C. Stennis Space Center (SSC) is postured to meet the testing demands of the next few years.

The John C. Stennis Space Center (SSC) is NASA's Lead Center for Rocket Propulsion Testing, giving the center oversight responsibility for all of NASA's rocket propulsion test assets. In addition, Stennis Space Center is the location of a variety of unique rocket propulsion test areas (A, B and E complexes) and capabilities [2-4]. Propulsion test services at SSC are available to NASA, Department of Defense (DoD), other government agencies, academia and industry.

The year 2000 has been an active one for large-scale propulsion testing at SSC as shown in Table 1. This table shows the test stand utilization for current and future years, and includes construction/reactivation periods (Con/Act) required to support the subsequent test program. Stand periods that are uncommitted at this time are also indicated as such. The general characteristics of each Test Complex and a profile of select current and future test programs are more fully addressed next.

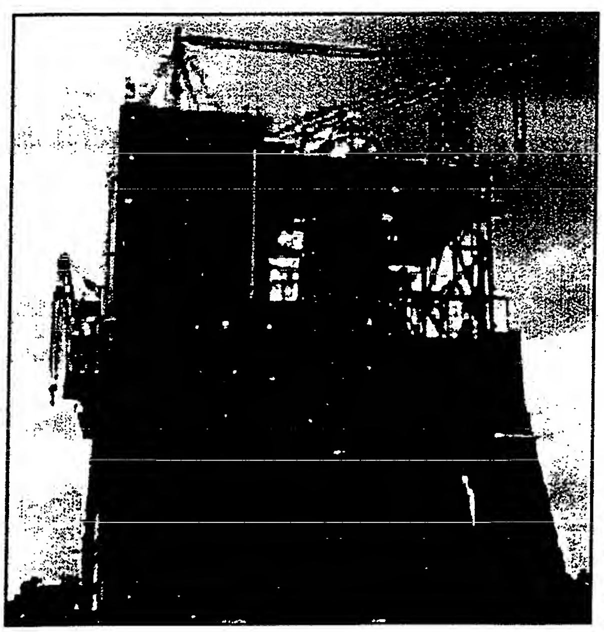
A Complex

The A Complex consists of the A1 and A2 test stands which are similar in design and are depicted in Fig. 1. Each test stand can be supplied with liquid hydrogen (LH_2) and liquid oxygen

Table 1. SSC Test Stand Utilization (Calendar Year)

Test Stand		2000				2001				2002				2003			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A1																	
A2																	
B1																	
B2																	
E1	Cell 1																
	Cell 2																
	Cell 3																
E2	Cell 1																
	Cell 2																
E3	Cell 1																
	Cell 2																
E4																	
H1		Mothballed															

Notes:
Con/Act: Construction and Reactivation tasks
[1] USFE Ph. 2, AR2-3 Ph. 2, P&W Ph. 2, Boeing, LMM


(a)

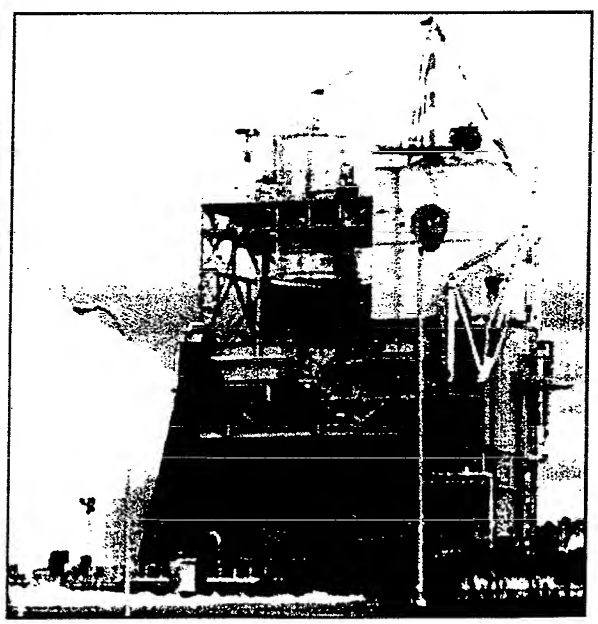

(b)

Fig. 1. A Complex: (**a**) Test stand A1 and (**b**) Test stand A2.

(LO_2) from low pressure run tanks, which are in turn filled/supplied from propellant barges via the canal system. The stands are also supplied with support fluids, gaseous helium (GHe), gaseous hydrogen (GH_2) and gaseous nitrogen (GN_2), for use as purge and pressurant gases. Each stand is designed for an approximate thrust load between $0.7 \cdot 10^6$ – $1.7 \cdot 10^6$ lb_f depending on the test article configuration. Further information regarding stand capabilities can be found in Ref. 2.

The A1 test stand schedule given in Table 1 shows continuous occupancy with the testing of Reusable Launch Vehicle (RLV) propulsion technology systems. Specifically, single-engine testing of the LO_2/LH_2-based Boeing Aerospike engine (XRS-2200) for the Lockheed-Martin X-33 demonstrator vehicle has just been concluded. This was preceded in the year 1999 by extensive testing of the Power Pack Assembly (PPA). Preparations are being made for testing of the *dual-engine* configuration of the XRS-2200 engine. Various flight acceptance and certification testing of the Space Shuttle Main Engine (SSME) continues to occur through 2003 at test stand A2.

B Complex

The B Complex, as shown in Fig. 2, is a dual-position system with one side of the stand designated as B1 and the other side designated as B2. Each test stand can be supplied with liquid hydrogen (LH_2) and liquid oxygen (LO_2) propellants from run tanks and a barge and canal system. The stands are also supplied with support fluids such as, for example, gaseous helium (GHe), gaseous hydrogen (GH_2) and gaseous nitrogen (GN_2) for use as purge and pressurant gases. Each stand is designed for an approximate thrust load between $6 \cdot 10^6$ – $11 \cdot 10^6$ lb_f depending on the test article configuration. Further information regarding stand capabilities can be found in Ref. 2.

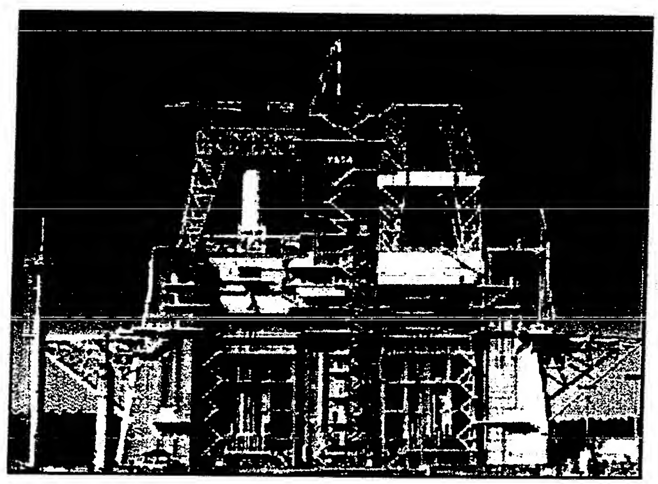


Fig. 2. B Complex with B1 on the left hand side and B2 on the right hand side.

B Complex activity is concentrated on the testing of propulsions systems for the Evolved Expendable Launch Vehicle (EELV) program, specifically the Boeing Delta IV vehicle. Testing of the Boeing LO_2/LH_2-based RS-68 engine is underway and continues beyond 2003 at test stand B1. Testing of the Common Booster Core (CBC) configuration (the RS-68 engine and its propellant tanks) shall begin in the current year on the B2 side and is scheduled to continue through part of 2001.

E Complex

The E Complex currently consists of three distinct test stands, E1, E2 and E3 with detailed stand capabilities delineated in Ref. 2. Notably, there are a total of *seven* test positions (or cells) offered within these three stands. The E1 test stand is comprised of three individual test cells

and is shown in Fig. 3. This versatile test stand can hence accommodate multiple programs and allows for testing of various combustion devices, turbopump assemblies and other rocket engine components. More specifically, E1 Cell 1 can handle liquid propellant-based and hybrid-based test articles up to $750 \cdot 10^3$ lb_f thrust (horizontal position). E1 Cells 2 and 3 are designed for various LO_2 and LH_2 turbopump assembly testing. The component testing is enabled here by the ability to supply extremely high-pressure propellants (up to 8500 psia) and gases (up to 13,500 psia) as required.

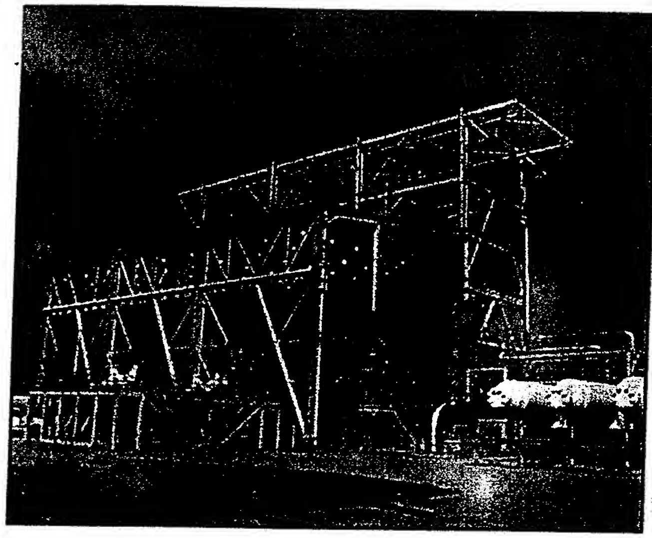


Fig. 3. E1 Test Stand comprised of Cells 1, 2 and 3.

The multi-cell E2 test stand was originally designed to support materials development for the National Aerospace Plane (NASP) program. The facility, which can handle thrust loads up to $100 \cdot 10^3$ lb_f, has recently been fully activated and used to perform pre-burner testing with LO_2 and RP1, and is currently being upgraded to accommodate component and engine development testing.

The E3 test stand consists of two individual test cells that are primarily designed for component and pilot-scale combustion device testing. E3 Cell 1 accommodates test articles up to $60 \cdot 10^3$ lb_f thrust (horizontal position) that employ the following propellant combinations: LO_2 or GO_2/hydrocarbon, GO_2/GH_2, and hybrid. LO_2/hydrocarbon and hybrid-based test articles can be tested at E3 Cell 2 up to thrust levels of $25 \cdot 10^3$ lb_f (vertical position). Notably, a unique and important feature of E3 Cell 2 is the capability to demonstrate hydrogen peroxide (H_2O_2) based test articles.

A variety of test programs and test facility upgrades occurred at the E Complex during the current year as shown in Table 1. Test stand E1 Cell 1 has been used this year to test TRW's Ultra Low Cost Engine (ULCE). Low cost is achieved through the use of a low-pressure combustion chamber (~700 psia), an ablative-lined chamber/nozzle, simplified propellant feed systems and a single pintle injector element [5].

TRW, Inc. has just completed demonstration of their Ultra Low Cost Engine (ULCE) pintle-based design with a nominal thrust of $650 \cdot 10^3$ lb_f using LO_2/LH_2 as propellants [6].
The TRW ULCE program consisted of a variety of tests from cold-flow activation tests (see Fig. 4a) to full-thrust ($650 \cdot 10^3$ lb_f) hot-fire tests this past year (see Fig. 4b). The culmination of the testing was a duration steady-state test at full thrust in late September 2000.

Future plans for E1 Cell 1 includes potential further testing of the TRW ULCE (Phase 2 and 3) and the $250 \cdot 10^3$ lb_f-thrust hybrid engine of the Hybrid Consortium that was previously tested at E1 Cell 1 in 1999.

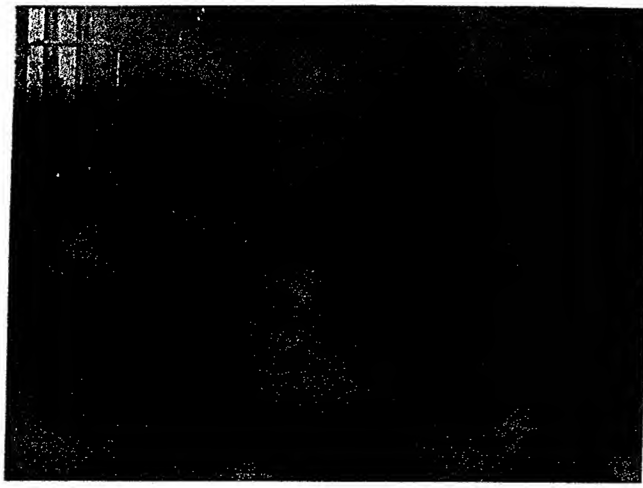


Fig. 4a. Cold-flow LO_2 activation test during the Ultra Low Cost Engine (ULCE) program at test stand E1 Cell 1. Flow is from left to right.

Fig. 4b. Hot-fire test of the TRW ULCE at E1 Cell 1.

Test stand E1 Cells 2 and 3 are currently being modified to enable testing of oxygen and hydrogen turbopumps (TP) and hydrogen preburner (PB) associated with the Integrated Powerhead Demonstrator (IPD) program. IPD integrated system testing is projected to follow circa 2003.

Phase 1 testing of an RS-76 LO_2-rich subscale preburner was completed in early 2000 at test stand E2 Cell 1. A unique facility accomplishment during this test program was the ability to operate both the LO_2 and RP1 run tanks at 7000 psia, while operating the respective pressurant nitrogen bottles for these propellants as high as 13,500 psia.

Activity at test stand E2 from mid-year 2000 to current has been confined to design, construction and activation tasks in preparation for potential programs including Fastrac (MC-1) and follow-on aspects of Phase 2 of the RS-76 LO_2-rich preburner.

Test stand E3 has been very active accommodating hybrid-based and H_2O_2-based test programs recently (see Table 1). Lockheed-Martin Michoud Space Systems has developed a $60 \cdot 10^3$ lb_f thrust Hybrid Sounding Rocket (HYSR) for use at Wallops Island [7]. An image of the HYSR installed at E3 Cell 1 is shown in Fig. 5. The HYSR was successfully demonstrated in multiple firings at E3 Cell 1 during the current year.

Hydrogen peroxide-based test articles such as the Boeing AR2-3, the Orbital Sciences Corporation Upper Stage Flight Engine (USFE) and Pratt and Whitney's Catalyst Bed have been recently tested at E3 Cell 2. SSC has gained experience in handling H_2O_2 concentrations up to 98% through conducting these programs.

Fig. 5. Hybrid Sounding Rocket (HYSR) installed at the E3 Cell 1 test stand [7].

Coupled with continuous upgrades of the existing E complex test stands, a new facility, termed E4, is being developed at SSC to accommodate Rocket Based Combined Cycle (RBCC) engine development. Sverdrup Technology, Inc. has developed an initial facility design, with details given in Ref. 8.

Succinctly, the E4 facility is expected to be a single-cell test stand to be developed in two phases and to be dedicated to the testing of large-scale RBCC test articles at high turnaround rates. Completion of Phase 1 (circa 2003) will enable sea-level static testing capability of RBCC test articles up to $50 \cdot 10^3$ lb_f thrust, which is consistent with sub-orbital demonstrator vehicle thrust requirements. Propellant capabilities of E4 will include hydrocarbon, LO_2 and H_2O_2 initially, with LH_2 capability added at a later date when needed. Assuming successful test results and continued engine endorsement, the E4 test stand will be upgraded during Phase 2 to allow for static sea-level RBCC engine testing up to $500 \cdot 10^3$ lb_f thrust, consistent with payload-carrying orbital launchers. In addition, an air blowdown capability may be added to the test stand as to allow for the testing of the RBCC engine at low Mach numbers ($M < 0.75$) at reduced thrust levels ($20 \cdot 10^3$ - $50 \cdot 10^3$ lb_f).

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REFERENCES

[1] NASA Marshall Space Flight Center web site content, http://std.msfc.nasa.gov.

[2] "Stennis Space Center Test Facilities Capabilities Handbook," edited by R. Bruce, Third Edition, Revision 1, July 1999.

[3] Rahman, S., Gilbrech, R., Lightfoot, R. and Dawson, M., "Overview of Rocket Propulsion Testing at NASA Stennis Space Center," 11th Annual Symposium on Propulsion, University Park, PA, November 18-19, 1999.

[4] Brogdon, T., Bruce, R. and Kahle, W., "NASA/Industry Cooperative Agreements for Engine, Component and Materials Testing at John C. Stennis Space Center," 31st AIAA/ASME/SAE/ASEE Joint Propulsion Conference, AIAA Paper 95-3007, San Diego, CA, July 10-12, 1995.

[5] Gavitt, K., Hardgrove, J., Mueller, T., Weede, J., Johnson, C. and Saville, M., "TRW's Ultra Low Cost LOX/LH_2 Booster Liquid Rocket Engine," 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, AIAA Paper 97-2818, Seattle, WA, July 6-9, 1997.

[6] "TRW's 650K Engine Second Largest Test," NASA SSC Newsletter Lagniappe, Vol. 23, Issue 9, September 2000.

[7] "New Hybrid Rocket Passes Key Test," NASA SSC Newsletter Lagniappe, Vol. 23, Issue 3, March 2000.

[8] Smith, K. and Wagner, D., "Development of Static Sea Level Test Facilities for RBCC Engines," 36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, AIAA Paper 2000-3602, Huntsville, AL, July 17-19, 2000.

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